Modeling Of The Molten Metal Hydrodynamics In Vacuum Arc Cathode Spots Using The Level-set Method

Anamaria Spataru[1], Helena T. C. Kaufmann[2]

[1]Siemens Energy S.R.L., Bucharest, Romania
[2]Siemens Energy Global GmbH & Co. KG Berlin, Germany

Abstract

The current and energy transfer to cathodes of vacuum arcs usually occurs in bright, narrow regions, known as cathode spots. Owing to extreme conditions in these spots, the cathode surface is eroded: electrode material is vaporized, and craters and molten metal jets are formed. The study of cathode spots of vacuum arcs is of significant interest in many industries and devices, such as vacuum interrupters or accelerators, since they affect their efficiency and operation stability.

Over the years, numerous models have been developed for the numerical simulation of cathode spots. A recent model, detailed in Ref. [1], simulates the hydrodynamics of the spot, on the basis of the heat transfer and Navier-Stokes equations and the particle level-set method. The present study centers on the implementation of the model of Ref. [1] in COMSOL Multiphysics and on the validation of the numerical methods for the simulation of phase change and surface deformation, and of the results.

The spatial and temporal distributions of the heat flux density to and the plasma pressure on the cathode surface were specified as input parameters. The dynamics of the molten metal were simulated by means of the Heat Transfer in Fluids and the Laminar Two-Phase Flow, Level Set interfaces, the latter available with the add-on CFD Module. The Application Libraries models "Rising Bubble" and "Continuous Casting - Apparent Heat Capacity Method" were used as examples of the implementation of the level-set and enthalpy-porosity methods in COMSOL Multiphysics. Special care was taken with the choice of parameters for both methods, as they can have a significant impact on the accuracy of the simulations results. In particular, an inappropriate choice of parameters will result in an interface too wide to properly and accurately resolve the head of the jet, or craters much deeper than they are wide; Fig. 1.

Simulations were performed for copper cathodes, subjected to a fixed energy flux density and different plasma pressures. The simulation results reveal the formation of a crater with an axially symmetric liquid-metal jet at the periphery, as a result of displacement of the molten material due to the pressure exerted by the plasma over the cathode surface, Fig. 2. The results of this study closely match the ones in Ref. [1]; some minor differences were identified, which can be attributed to the different chosen material properties and numerical methods used.

The model and results presented in this work served as validation of the hydrodynamic part of a detailed model of cathode spots in vacuum arcs, which describes all key mechanisms occurring in the spot (including current transfer and the vaporization of the cathode material in the spot, its subsequent ionization and the interaction of the produced plasma with the cathode) [2].

Reference

[1] G. A. Mesyats and I. V. Uimanov, "Hydrodynamics of the Molten Metal During the
Crater Formation on the Cathode Surface in a Vacuum Arc" IEEE Trans. Plasma Sci. 43, 2241 (2015).
[2] H. T. C. Kaufmann, et al., “Detailed numerical simulation of cathode spots in vacuum arcs: Interplay of different mechanisms and ejection of droplets”, J. Appl. Phys. 122, 163303 (2017).

Figures used in the abstract

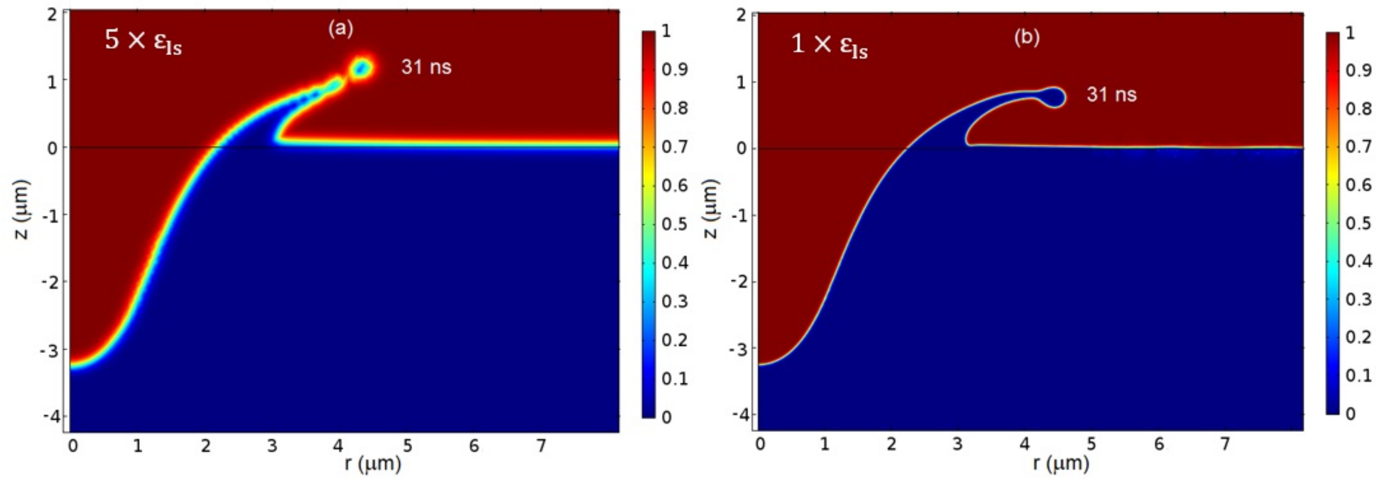

Figure 1 : Jet formation and distribution of the level-set function computed with two different values of the parameter for the thickness of the interface.

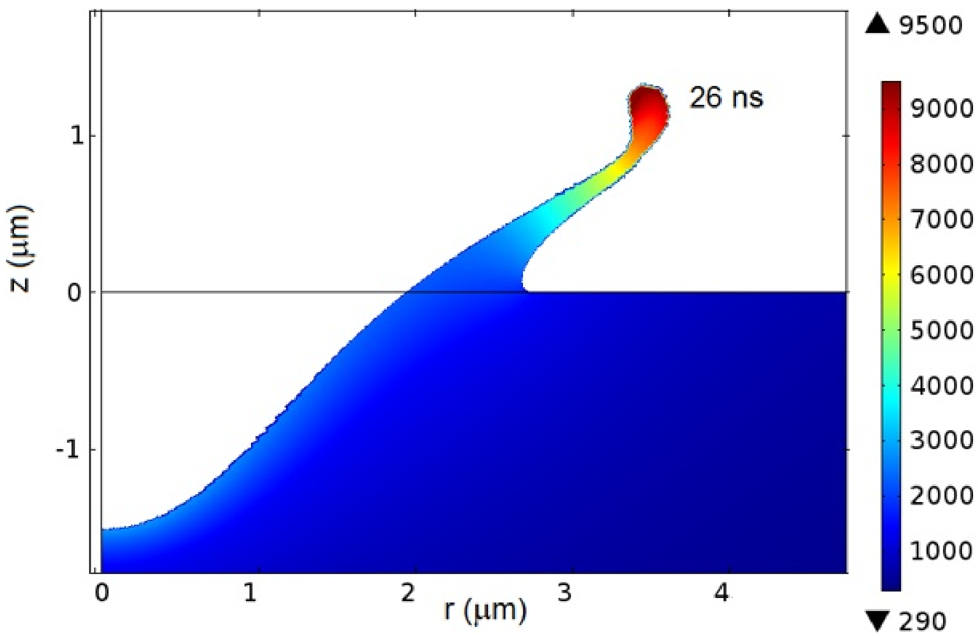

Figure 2 : Temperature distribution and crater and jet formation computed with the model of this work for the same conditions as those of Ref. [1]. The bar in K.

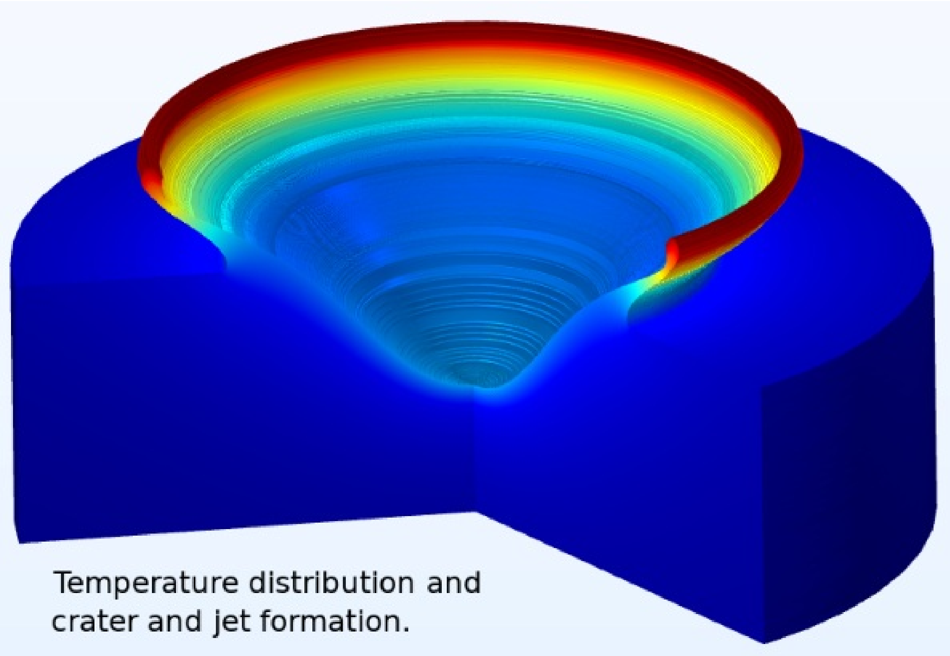

Figure 3 : thumbnail image